Extending the 5G user experience into the home with Wi-Fi 6

Due to its plug-and-play, robust operation, large eco-system and low cost, Wi-Fi has become the dominant technology for wireless connectivity. However, this wide proliferation also comes with a downside: multiple unmanaged networks competing for capacity in crowded, and congested environments. Compare this to a cellular network, where a single operator is licensed to operate on each block of spectrum and can manage and control their full network over a wide area. Taking hints from cellular, Wi-Fi 6 adopts a more managed approach to networking, to continue operating reliably in crowded and congested environments, and to increase throughput by a factor of four in these scenarios compared to Wi-Fi 5.
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Evolution of 802.11

Wi-Fi performance has steadily improved over the last 20 years, as shown in Figure 1. Wi-Fi 4 (802.11n) introduced channel bonding and single user MIMO allowing 150 Mb/s per stream and up to four spatial streams to a single user. Wi-Fi 5 (802.11ac) introduced multi-user MIMO to up to four users in the downstream direction with up to eight total spatial streams, and higher order modulation. The theoretical capacity of a Wi-Fi 5 access point (AP) is 6.9 Gb/s although this capacity is not achievable in practice. Wi-Fi 6 (802.11ax) adds multi-user MIMO in the upstream direction with up to eight spatial streams in both the upstream and downstream directions, and higher order modulation. The theoretical capacity of a Wi-Fi 6 AP is 9.6 Gb/s. Improvements described in the next section allow the capacity experienced by users to be closer to the theoretical capacity than for Wi-Fi 5. Indeed, Wi-Fi 6 can provide four times the capacity of Wi-Fi 5 in dense environments.

Figure 1. Peak rate evolution of the different 802.11 standards

- **Wi-Fi 4 (802.11n)**
  - Up to 64 QAM
  - Channel bonding
  - Single-user MIMO

- **Wi-Fi 5 (802.11ac)**
  - Up to 256 QAM
  - Multi-user MIMO (downlink)

- **Wi-Fi 6 (802.11ax)**
  - Up to 1024 QAM
  - Multi-user MIMO (uplink)
  - OFDMA
Wi-Fi 6: A giant leap forward

Wi-Fi 6 is the first new generation of Wi-Fi that does not dramatically increase the peak rate of the Wi-Fi technology. Rather, it adopts features that are primarily aimed to improve capacity, spectrum efficiency, and latency in dense deployments with heavily loaded networks, whether they be private or public. Here are some of the key features of Wi-Fi 6.

- **Uplink and downlink orthogonal frequency division multiple access (OFDMA)** tightly orchestrates how the spectrum is accessed by all devices in the network, reducing contention, increasing determinism and reliability. OFDMA subdivides a channel into small frequency allocations so that multiple users (typically up to 30) can use the same channel quasi-simultaneously. This increases efficiency and lowers latency for both downstream and upstream traffic.

- **Multi-user MIMO (MU-MIMO)** allows multiple streams of data to be transferred at the same time in the same channel. This allows several high-bandwidth applications to run concurrently, increasing the network capacity and efficiency. Wi-Fi 6 extends downlink MU-MIMO to eight spatial streams (compared to four streams in Wi-Fi 5) and adds eight uplink spatial streams MU-MIMO (only one spatial stream in Wi-Fi 5).

- **Beamforming** improves signal strength and reduces interference.

- Increased spatial re-use is enabled through the **BSS coloring mechanism**. This mechanism enables a device to quickly discard a packet when it’s not the intended receiver.

- The better interference control and improved signal strength provided by the previous four features can be further exploited by a **higher modulation mode** (1024 QAM), which enables higher peak speeds. Higher modulation order and other improvements lead to a PHY rate of 1200 Mb/s per 160 MHz channel, up from 867 Mb/s in Wi-Fi 5, which represents a 39% increase.
- **Increased symbol durations** for longer-range communications. This is especially useful for outdoor environments.

- A **wider channel capability** offers the possibility for higher peak rates but reduces the number of non-interfering channels in the band.

- **Targeted wake time (TWT)** schedules sleep and wake times for longer battery life. This is particularly beneficial for IoT applications.

- **New spectrum in the 6 GHz band** is expected to become available for use by Wi-Fi 6. Devices using previous generations of Wi-Fi will not operate in this clean band so the full benefits of Wi-Fi 6 will not be compromised by sharing spectrum with legacy Wi-Fi devices.

- The **new security standard, WPA3**, required for Wi-Fi 6 certification, will allow devices to access and authenticate more easily with the Wi-Fi network. But it also better protects the user when accessing public hot spots.

**What about 5G?**

At first glance it does not seem evident, but Wi-Fi has played a significant role in the success of cellular networks by acting as the last hop towards the WAN gateway for the majority of mobile device traffic (see Figure 3) and providing coverage where cellular networks struggle.

**Figure 3. Fixed/Wi-Fi traffic will take up half of the total consumed traffic annually**

Relying on the availability of Wi-Fi, cellular network providers have been able to lower the investment required to provide reliable, high-performance services to mobile devices. Today, the interplay between Wi-Fi and cellular is happening between LTE and Wi-Fi 5.

With the advent of 5G, improvements in efficiency and latency compared to LTE networks are likewise matched by Wi-Fi 6’s improvements in efficiency and latency compared to Wi-Fi 5 networks. Therefore, we can expect Wi-Fi 6 to continue to play a significant role as a complement to 5G networks. This could be particularly important for mmWave 5G networks where Wi-Fi-6 can provide indoor coverage where...
mmWave 5G can’t. As Wi-Fi 6 can support many of the use cases targeted for 5G (see Table 1), especially non-mobile and residential, users will not notice any service degradation when offloading to the fixed/Wi-Fi network.

Table 1: Both 5G and Wi-Fi 6 substantially improve performance over their respective predecessors. This will allow the current synergy between cellular, and Wi-Fi networks to continue.

<table>
<thead>
<tr>
<th>Feature</th>
<th>5G</th>
<th>Wi-Fi 6</th>
</tr>
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<tbody>
<tr>
<td>Spectrum availability</td>
<td>Regional dependency</td>
<td>Global</td>
</tr>
<tr>
<td>Reliability (when deployed under SLA)</td>
<td>3GPP mandated E2E management</td>
<td>(can be) E2E managed</td>
</tr>
<tr>
<td>Security</td>
<td>Mission-Critical</td>
<td>Business-critical</td>
</tr>
<tr>
<td>User-experienced data rates</td>
<td>100+ Mb/s</td>
<td>100+ Mb/s</td>
</tr>
<tr>
<td>Peak data rate</td>
<td>10 Gb/s</td>
<td>10 Gb/s</td>
</tr>
<tr>
<td>Range</td>
<td>1 km</td>
<td>150 m</td>
</tr>
<tr>
<td>Transmission latency (theoretical minimum)</td>
<td>0.15 ms</td>
<td>0.12 ms</td>
</tr>
<tr>
<td>Mobility</td>
<td>500 km/h</td>
<td>10 km/h</td>
</tr>
<tr>
<td>Battery life</td>
<td>3 days* (smartphone)</td>
<td>15 years* (IoT device)</td>
</tr>
<tr>
<td></td>
<td>+ 67% **</td>
<td></td>
</tr>
<tr>
<td>Connection density</td>
<td>10⁶/km²</td>
<td>10⁶/km²</td>
</tr>
</tbody>
</table>

Together, Wi-Fi 6 and 5G will cover the full range of use cases that will be developed, ranging from wide-area, power-limited IoT networks, over stadiums, and theaters, to Industry 4.0. Wi-Fi will continue to serve as the wireless network of choice in most indoor (residential) applications due to the lower cost, enormous ecosystem and performance good enough for all but the most demanding applications. 5G will play its part in most outdoor locations due to the stronger support of mobility, lower latency and wider coverage.
Acronyms

ACS          Automatic channel selection  
AP           Access point                 
CPE          Customer premises equipment 
CSP          Communications service provider  
DCS          Dynamic channel selection   
IEEE         Institute of Electrical and Electronics Engineers 
ICS          Intelligent Channel Selection 
IoT          Internet of Things         
LTE          Long-term evolution         
MIMO         Multiple-input and multiple-output 
MU-MIMO      Multi-user MIMO (MU-MIMO)    
OFDMA        Orthogonal frequency division multiple access 
PBC          Push Button Configuration   
QAM          Quadrature amplitude modulation 
QR           Quick response code        
SSID         Service Set Identifier     
WAN          Wide area network          
WFA          Wi-Fi Alliance             
WPA          Wi-Fi Protected Access     
WPS          Wi-Fi Protected Setup